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ADAPTIVE CHANNEL FILTRATION FOR COMMUNICATIONS SYSTEMS

BACKGROUND OF THE INVENTION

Technical Field of the Invention

The present invention relates in general to the field of communications systems, and in particular, by way of example but not limitation, to adaptive channel filtrations that are responsive to relative levels of received signal power in wireless communications systems.

Description of Related Art

Mobile wireless communication is becoming increasingly important to both individuals and organizations for providing safety, convenience, improved productivity, and simple conversational pleasure to subscribers of wireless communications services. One prominent mobile wireless communication option is cellular communication. Cellular phones, for instance, can be found in cars, briefcases, purses, and even pockets. While the number of cellular phone subscribers continues to rise, the types and quality of services being demanded by cellular phone subscribers are dramatically rising as well. One type of service whose popularity has been skyrocketing, especially with the emerging prominence of e-mail, faxing, and the Internet, is data transmission.

Data may be transmitted on, for example, existing voice, data, and/or control channels. However, many of the new features that subscribers are demanding require extraordinarily high data transfer rates that cannot be effectively provided by existing channels. New mechanisms

for transmitting at extraordinarily high data rates are needed to meet the demand. In accordance with the Global System for Mobile Communications ++ (GSM++) standard, a new scheme termed "Enhanced Data rates for Global Evolution" (EDGE) is under development. EDGE is intended to increase the data transfer rate available to mobile users.

EDGE systems achieve a high data transfer rate by changing the coding and modulation. Consequently, EDGE systems need a higher Carrier-to-Interference (C/I) performance ratio to achieve the intended higher data transfer rates. However, normal GSM cell planning specifications are used when designing EDGE systems so as not to reduce the total number of subscribers that may be accommodated by a given system. Because GSM cell planning specifications are reused, the requirements relating to adjacent channel rejection (C/I_{A1}) are of the same magnitude as for an ordinary GSM system. As a result, EDGE channel filters should not only avoid disturbing the C/I-performance, but they should also be capable of meeting the ordinary GSM adjacent channel requirements.

Conventional approaches are directed to optimizing the channel filter for the best compromise between adjacent channel rejection (C/I_{A1}) and co-channel (C/I) performance. This compromise, by definition, is optimal for only a single situation, if any. Consequently, receivers using the conventional approach are sub-optimal in most situations inasmuch as they use a fixed, pre-set compromise between adjacent channel rejection and co-channel performance.

SUMMARY OF THE INVENTION

The deficiencies of conventional approaches are overcome by the method, system, and arrangement of the present invention. For example, as heretofore unrecognized, it would be beneficial if the channel filter could be adaptively optimized responsive to current channel conditions. In fact, it would be beneficial if the channel filter could be adaptively optimized responsive to current Rayleigh-fading conditions.

In accordance with principles of certain embodiment(s) of the present invention, the optimal channel filter design changes along with the Rayleigh-fading in Rayleigh-faded environments. Also, the channel filter can be advantageously changed on a burst basis so that optimal performance is achieved in Rayleigh-fading environments, instead of merely in a predicted average environment. Principles of the present invention may be incorporated into a homodyne-based receiver architecture. In an exemplary homodyne-based receiver, the power of the adjacent channel interferer is calculated (e.g., determined, estimated, etc.), and an

associated channel filter is adapted depending on the ratio between the total power (e.g., the desired channel plus the adjacent channel) and the adjacent channel power.

In one or more embodiments, the ratio between the total power and the adjacent channel power is used with a look up table to produce a needed channel filter bandwidth. (The look up table may be derived, for example, from a graph of frequency versus power spectrum magnitude.) The channel filter bandwidth may be relied on to create coefficients for utilization by a low pass filter. The low pass filter therefore optimally and adaptively filters out the adjacent channel in favor of the desired signal.

The above-described and other features of the present invention are explained in detail hereinafter with reference to the illustrative examples shown in the accompanying drawings. Those skilled in the art will appreciate that the described embodiments are provided for purposes of illustration and understanding and that numerous equivalent embodiments are contemplated herein.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the method, system, and arrangement of the present invention may be had by reference to the following detailed description when taken in conjunction with the accompanying drawings wherein:

FIGURE 1 illustrates an exemplary portion of an exemplary wireless network system with which the present invention may be advantageously practiced;

FIGURE 2 illustrates an exemplary homodyne-based receiver architecture that may be implemented in the exemplary wireless network system of FIGURE 1;

FIGURE 3A illustrates an exemplary homodyne-based receiver architecture in accordance with the present invention that may be implemented in the exemplary wireless network system of FIGURE 1;

FIGURE 3B illustrates a portion of the exemplary homodyne-based receiver architecture of FIGURE 3A in accordance with the present invention that may be implemented in the exemplary wireless network system of FIGURE 1;

FIGURE 4 illustrates an exemplary graph of frequency versus power spectrum magnitude;

FIGURE 5 illustrates an exemplary table with an exemplary relationship between adjacent channel rejection and channel filter bandwidth;

FIGURE 6A illustrates an exemplary method in flowchart form for adaptively filtering a signal in accordance with the present invention; and

FIGURE 6B illustrates another exemplary method in flowchart form for adaptively filtering a signal in accordance with the present invention.

DETAILED DESCRIPTION OF THE DRAWINGS

In the following description, for purposes of explanation and not limitation, specific details are set forth, such as particular circuits, logic modules (implemented in, for example, software, hardware, firmware, some combination thereof, etc.), techniques, etc. in order to provide a thorough understanding of the invention. However, it will be apparent to one of ordinary skill in the art that the present invention may be practiced in other embodiments that depart from these specific details. In other instances, detailed descriptions of well-known methods, devices, logical code (e.g., hardware, software, firmware, etc.), etc. are omitted so as not to obscure the description of the present invention with unnecessary detail.

A preferred embodiment of the present invention and its advantages are best understood by referring to FIGURES 1-6B of the drawings, like numerals being used for like and corresponding parts of the various drawings. Aspects of the GSM standard will be used to describe an embodiment of the present invention. However, it should be understood that the

principles of the present invention are applicable to other wireless communication standards (or systems), especially those that can benefit from C/I and C/I_{A1} performance compensation.

With reference to FIGURE 1, an exemplary portion of an exemplary wireless network/communications system with which the present invention may be advantageously practiced and/or employed is illustrated generally at 100. The (portion of) wireless communications system 100 includes a cell 105 that is served by a base station (BS) 110. The BS 110 typically includes a base transceiver station (BTS) 110A and optionally includes a BS controller (BSC) 110B. Within the cell 105 are multiple mobile terminals (MTs) (e.g., mobile stations (MSs), etc.) 115A and 115B, each of which may be in communication with the wireless network infrastructure as represented by the BS 110. Each MT 115 may be, for example, a hand-held cellular phone (e.g., the MT 115A), a vehicle-mounted MT (e.g., the MT 115B), a data terminal with a wireless link (not specifically shown), etc. While only two MTs 115 are shown in the wireless communications system 100, many more MTs 115 are usually present within each such cell 105. Also,

it should be noted that the wireless communications system 100 is usually composed of many such cells 105 and BSs 110.

With reference to FIGURE 2, a homodyne-based receiver architecture that may be implemented in the exemplary wireless network system of FIGURE 1 is illustrated generally at 200. The receiver architecture 200 includes branches for both the in-phase (I)-channel and the quadrature-phase (Q)-channel. Sigma-delta analog-to-digital (A/D)-converters 205 may operate at an exemplary forty-eight (48) times over sampling. The sigma-delta A/D-converters 205 convert the received analog signal to a digital format for signal manipulation. The exemplary 48 times oversampling ratio is adequate to achieve a dynamic range that is required by the GSM standard without needing an Automatic Gain Control (AGC).

The receiver architecture 200 also includes three (e.g., digital) low pass (LP) filters 210,220,230 and three decimation blocks 215,225,235. The three LP filters 210,220,230 remove noise and received interfering signals from the desired signal. The LP-filtering also enables decimation of the received data without having the noise or received interfering signals folded into the spectrum of the

desired signal. The LP filters 230 are the narrowest filters. They are used to filter out the desired channel and to block the first adjacent channel, and they are typically the most complex filters. The optimal bandwidth of these LP filters 230 are set based on the adjacent channel GSM requirements. The decimation blocks 215,225,235 reduce the data rate by the exemplary "12", "2", and "2" decimation factors, respectively.

Because the received signal is converted down to direct current (DC) in homodyne receivers, it is necessary for the received signal to be separated from the DC-offset produced by imperfections in the homodyne receiver. To meet this need, the DC-offset is subtracted from the received signal. The DC-level calculation block 240 calculates the average DC value during, e.g., a received burst. Meanwhile, the received signal is stored in a memory 245 (e.g., a first-in first-out (FIFO) memory) while the average DC value is being calculated by the DC-level calculation block 240. After the average DC-offset is calculated by the DC-level calculation block 240, the average DC value may be subtracted from the DC-level of the received signal at the subtraction blocks 250

for both of the I-channel and the Q-channel components to correct for the DC-offset. The DC-offset-corrected signals for both of the I-channel and the Q-channel components may thereafter be forwarded from the subtraction blocks 250.

With reference to FIGURE 3A, an exemplary homodyne-based receiver architecture in accordance with the present invention that may be implemented in the exemplary wireless network system of FIGURE 1 is illustrated generally at 300. The receiver architecture 300 includes branches for both the I-channel and the Q-channel. Sigma-delta A/D-converters 305 may operate at an exemplary forty-eight (48) times over sampling. The sigma-delta A/D-converters 305 convert the received analog signal to a digital format for enhanced signal manipulation. The exemplary 48 times oversampling ratio is adequate to achieve a dynamic range that is required by the GSM standard without needing an AGC; however, it should be noted that other oversampling values may be utilized without departing from the scope of the present invention.

The receiver architecture 300 also includes two initial (e.g., digital) LP filters 310,320 and two initial decimation

blocks 315,325. The two LP filters 310,320 remove noise and received interfering signals from the desired signal. The LP-filtering also enables decimation of the received data without having the noise or received interfering signals folded into the spectrum of the desired signal. The decimation blocks 315,325 reduce the data rate by the exemplary decimation factors of "12" and "2", respectively. To remove the DC offset present in homodyne-based receivers, the DC-offset may be subtracted from the received signal. The DC-level calculation block 330 may calculate the average DC value during, e.g., a received burst. It should be noted that other time periods can alternatively be used. Additionally, the received signal may be stored in a memory 335 (e.g., a FIFO memory) while the average DC value is being calculated by the DC-level calculation block 330. After the average DC-offset is calculated by the DC-level calculation block 330, the average DC-offset value may be subtracted from the DC-level of the received signal at the subtraction blocks 340 for both of the I-channel and the Q-channel components to correct for the DC-offset.

In contrast with the receiver architecture 200, the receiver architecture 300 includes at least one variable (e.g., adjustable) LP filter 350 for filtering out the desired channel and for blocking the first adjacent channel. The optimal filter bandwidth of these LP filters 350 may be established by adjusting the controlling coefficients based on the relative signal strengths of the desired and adjacent channels. The filter coefficient determiner 345 may receive as input the I-channel and Q-channel component outputs from the decimators 325 on paths 345I and 345Q, respectively. The filter coefficient determiner 345, an embodiment of which is described in greater detail hereinbelow with reference to FIGURE 3B, determines appropriate coefficients for establishing an optimal filtering bandwidth for LP filters 350. These coefficients, or other control signal(s) for defining the bandwidth of a filter, are provided to the LP filters 350 on path(s) 345C. After the LP filtering by the LP filters 350, decimation blocks 355 reduce the data rate by the exemplary decimation factor of "2". The resulting signals for both of the I-channel and the Q-channel

components may be forwarded thereafter for further processing.

With reference to FIGURE 3B, a portion of the exemplary homodyne-based receiver architecture 300 of FIGURE 3A in accordance with the present invention that may be implemented in the exemplary wireless network system of FIGURE 1 is illustrated at 345. An I-channel and a Q-channel component are received as input at the filter coefficient determiner 345 on paths 345I and 345Q, respectively. An I-channel and a Q-channel component are fed to high pass (HP) filters 360. The resulting HP filtered signals are forwarded to an amplitude/power calculation #1 block 365, which determines the amplitude of the adjacent channel power (e.g., of the adjacent channel interferer). An I-channel and a Q-channel component are also fed to an amplitude/power calculation #2 block 370, which determines the amplitude of the total power. Coefficient determination may be made based on the relationship between the total power and the adjacent channel power. In an exemplary GSM embodiment, the calculation of such a relationship between the adjacent channel and the

wanted signal is performed at two times the GSM rate (e.g., F_S=2*13/48 MHz).

The power calculations in the amplitude/power calculation #1 block 365 and the amplitude/power calculation #2 block 370 may be performed in a myriad of manners and with various numbers of samples, depending on the desired accuracy. An economical option is to "reuse" the hardware (not explicitly shown) that is used to calculate the power after the last channel filter (also not explicitly shown) of the exemplary homodyne-based receiver architecture 300 of FIGURE 3B. In certain embodiments, the power calculations may be accomplished by estimating the amplitude with the following exemplary approximation: Amp = Max (I,Q) + 0.5 * Min(I,Q). It should be noted that other approximations or more exact techniques may be employed without departing from the scope of the invention. It should be understood that "calculate/calculation/etc.", as they are used in this disclosure, encompass and embrace, at least, calculate, determine, estimate, ascertain, approximate, etc. Each of the amplitude/power calculation #1 block 365 and the amplitude/power calculation #2 block 370 forward their

respective amplitude calculations to select filter coefficient(s) block 375. The select filter coefficient(s) block 375 may use an average relationship between the amplitude calculation results of the amplitude/power calculation #1 block 365 and the amplitude/power calculation #2 block 370 to determine the filter coefficients for the LP channel filters 350 (of FIGURE 3A). The filter coefficient(s) are passed from the select filter coefficient(s) block 375 to the LP channel filters 350 via path(s) 345C. In one embodiment, as is described in greater detail hereinbelow with reference to FIGURES 4 and 5, the filter coefficient(s) selection performed by the select filter coefficient(s) block 375 may be accomplished by linking different stored coefficients with/to different correspondence relationships between calculated amplitudes and filter bandwidths. It should be noted that the choice of the HP filter type may also impact performance, but such a choice should not be an overly critical aspect of performance.

The receiver architecture 300, using the filter coefficient determiner 345, enables the LP filters 350 to be

adaptively optimized for both co-channel and adjacent channel rejection performance. It should be noted that in certain embodiments, a trade off exists between the adjacent channel suppression and the link performance (e.g., as measured by block error rate (BER) and raw bit error). Simulations have indicated that the position of the "BER-knee" (e.g., in graphs of C/I versus uncoded block error (UBLER)) changes with the simulated C/I. It should further be noted that the limiting factor on the C/I performance for the complete MT or BS therefore needs to be known before the filters are designed in order to prevent the channel filter from limiting the overall performance. Simulations have also indicated the existence of a trade off between adjacent channel suppression and the maximum C/I performance attainable without any significant degradation of the performance due to the filters. As a result, if/when the maximum C/I is set to a lower value by other parts of the, e.g., MT or BS, then it is possible to increase the adjacent channel rejection without any significant loss in the overall performance.

Continuing now with FIGURE 3B, the amplitude/power calculation #1 block 365 calculates the power of the adjacent

channel, and the amplitude/power calculation #2 block 370 calculates the power of the sum of the wanted signal and the adjacent channel. The ratio $P_{C/I}$ is determined therefrom as follows:

$$P_{C/I} = \frac{P_{Amp...calc...\#2...block} - P_{Amp...calc...\#1...block}}{P_{Amp...calc...\#1...block}} = \frac{C}{I_{Adj200kHz}}$$

It should be noted that the "200 kHz" is exemplary only, and other adjacent channel frequency values may be selected. Advantageously, if the signal values are converted into logarithmic amplitude(s) (e.g., by using existing hardware), such a calculation of a relationship involving the adjacent channel power and the total power transforms from a division to a simpler subtraction. In accordance with certain principles of the present invention, the ratio $P_{C/I}$ may be used to determine the optimal bandwidth of the adjacent

channel filter as is described further with reference to FIGURES 4 and 5.

With reference to FIGURE 4, an exemplary graph of frequency versus power spectrum magnitude is illustrated generally at 400. In the graph 400 (which may be calculated using, for example, a commercial simulator such as Matlab), the wanted signal 405 is plotted together with multiple levels of interferer 410A-G so that the ratio $P_{C/I}$ may be used to determine the optimal bandwidth of the adjacent channel filter. The graph 400 covers the range $C/I_{Adj200kHz}$ = -12 to +6 dB in steps of 3dB. (It should be noted that the power levels in the graph 400 may appear to be 3 dB too low. However, the interference spectrum is only plotted in the (exemplary) graph 400 for positive frequencies, so there should be identical copies centered at -200 kHz. In other words, half of the energy in the interfering signal is located at positive frequencies and half of the energy is located at negative frequencies.)

The graph 400 may be used to create a correspondence relationship between wanted bandwidth and the ratio $C/I_{Adj200kHz}$. For example, a look up table of wanted bandwidth

as a function of the ratio $C/I_{Adj200kHz}$ may be established. Such a correspondence (e.g., a look up table, data structure, etc.) may be stored in a memory 380 (of FIGURE 3B), for example. Other techniques for storing or accessing the correspondence may alternatively be employed. In one embodiment, the bandwidth of the channel filter may be set by the point where the power of the interferer 410A-G equals the power of the wanted signal 405. With respect to interfering signal 410G, for example, the wanted signal 405 is equal to the interfering signal 410G at approximately -12 dB along the y-axis (ordinate). The corresponding frequency along the x-axis (abscissa) is approximately 122 kHz, which results in a needed filter bandwidth of 78 kHz for the LP filters 350.

With reference to FIGURE 5, an exemplary table with an exemplary correspondence relationship between adjacent channel rejection and channel filter bandwidth is illustrated generally at 500. The table 500, or an equivalent data structure, may be stored in, for example, the memory 380 (of FIGURE 3B). The table 500 provides a correspondence between the ratio $C/I_{Adj200kHz}$ in dB of column 505 and the filter

bandwidth (BW) value in kHz of column 510. The first row, for instance, provides the above-explained correspondence between -12 dB in the column 505 of the interfering signal (410G) and the corresponding filter BW of 78 kHz in the column 510. A set of different filter coefficients for each bandwidth of a filter BW collection (such as that provided in the column 510) may be pre-calculated and stored in a memory, such as the memory 380, in manner(s) known to those of ordinary skill in the art. For example, given the bandwidth and the complexity of the intended filter, it is possible to calculate appropriate coefficients using, e.g., a commercial simulator. It should be noted that the memory may be different from the memory used to store the table 500 and that the memory 380 may be constituted of one or more of many different available memory types, such as read-only memory (ROM). The stored filter coefficients, once retrieved, may be forwarded along path(s) 345C (of FIGURE 3B). In this manner, differing sets of filter coefficients can be employed depending on the calculated power ratio $C/I_{Adj200kHz}$, thereby adapting the filtering parameters to the current operating conditions.

With reference to FIGURE 6A, an exemplary method in flowchart form for adaptively filtering a signal in accordance with the present invention is illustrated generally at 600. A signal is received at a receiver (e.g., a receiver of an MT or a BS) (step 605). The received signal is split into I-channel and Q-channel components (step 610). The split I-channel and Q-channel components are low pass filtered and decimated one or more times (step 615). The DC-offset (e.g., if the receiver is a homodyne receiver) is removed (step 620). Either before, during, and/or after (e.g., depending on relative durations and/or whether DC-offset removal is performed), filter coefficient(s) are determined (step 625). The filter coefficient(s) may be determined, for example, based on relative signal strengths of the received signal(s). The signal resulting from the DC-offset removal is low pass filtered using the determined coefficient(s) (step 630). The low-pass-filtered signal may then be decimated (step 635) before being forwarded for further processing.

With reference to FIGURE 6B, another exemplary method in flowchart form for adaptively filtering a signal in

accordance with the present invention is illustrated generally at 650. The flowchart 650 may be part of a larger scheme and correspond to, for example, the step 625 of the flowchart 600 of FIGURE 6A. The flowchart 650 begins by receiving I-channel and Q-channel components (step 655). These I-channel and Q-channel components may optionally have already been low pass filtered and decimated (e.g., as performed in the step 615 of the flowchart 600 of FIGURE 6A). The I-channel and Q-channel components each follow two paths. One set of the I-channel and Q-channel components are high pass filtered (e.g., to attempt to isolate the adjacent channel interferer(s)) (step 660). After high pass filtering, the amplitude/power of the adjacent channel may be calculated (step 665).

For another set of the I-channel and Q-channel components, the amplitude/power of the desired signal as well as the adjacent channel (e.g., the total power) may be calculated (step 670). The results of the two amplitude/power calculations (from steps 665 and 670) may be used to determine the C/I power ratio (step 675). From the C/I power ratio, the optimal bandwidth of an adjacent channel

filter is determined (step 680). Filter coefficients for the adjacent channel filter may be determined based on the determined optimal bandwidth (step 685). The determined filter coefficients may be used by a low pass filter for filtering out an adjacent channel interferer (e.g., as performed by the step 630 in the flowchart 600 of the FIGURE 6A).

Although preferred embodiment(s) of the method and system of the present invention have been illustrated in the accompanying Drawings and described in the foregoing Detailed Description, it will be understood that the present invention is not limited to the embodiment(s) disclosed, but is capable of numerous rearrangements, modifications, and substitutions without departing from the spirit and scope of the present invention as set forth and defined by the following claims.